Physics with stopping muons in Daya Bay

1. Introduction
2. Stopped muons/AD/year
3. μ^--C capture rate
4. μ^--Gd capture rate
5. Cosmic muon charge ratio

Technical note in doc-2232.

Introduction

- Roughly 2% and 5% of muons incident on the far and near sites will stop in the water pools, respectively.
- Only consider stopping muons in AD at near sites because flux$\times$stopping rate is 50 times lower at far site and products of stopped muons create too few PE in water pool.

The possible measurements are

1. The cosmic muon charge ratio,
2. The neutron multiplicity from μ^-C captures, and
3. The μ^- capture rate on gadolinium.

Estimate of number of stopped muons/AD/year

- 5% of incident muons stop in water pool
- cosmic muon rate is 1.2(0.7) $\mathrm{Hz/m^2}$ at the Daya Bay(Ling Ao) near sites
- OAV volume / rectangular pool volume is $4\pi 2^2/(16 \times 10 \times 10) \approx 1/10\pi$

$$1\mathrm{Hz/m^2} \times (16 \times 10\mathrm{m^2}) \times 0.05 \times 1/(10\pi) \times \pi \times 10^7 \mathrm{s/yr} \approx 8 \times 10^6/\mathrm{AD/yr} \tag{1}$$

μ^--C capture rate

The cosmic μ^+/μ^- charge ratio is approximately 1.3 and $\sim$8% of the stopped μ^- are captured on carbon, so the number of μ^- captures on carbon is

$$8 \times 10^6 \times 1/(1+1.3) \times 0.08 \approx 2.8 \times 10^5 \text{captures/AD/yr} \quad . \qquad (2)$$

This is comparable to the sample of 1.8×10^5 μ^--^{12}C captures in a published result on n-emission after μ^--C capture.
We could measure

1. neutron multiplicity
2. neutron energy (requires inferring energy from distance between muon track endpoint and neutron capture point)

μ^--Gd capture rate

- Rough estimate of relative rate of μ^- capture on Gd compared to C with the "Fermi-Teller Z law" which assumes that the capture rate is proportional to Z and the concentration of Gd.
- Assuming GdLS is 0.1% Gd and 90% C by weight, the relative capture rate is $0.1/90 \times 64/6 \approx 0.012$.
- Negative muon captures on Gd can only occur in the inner acrylic volume which is $(3.10/3.97)^3 = 0.476$ of the OAV so the estimated rate of μ^--Gd captures is

$$2.8 \times 10^5 \ \mu^-\mathrm{C/AD/yr} \times 0.476 \times 0.012 \approx 1600 \ \mu^-\mathrm{Gd/AD/yr} \quad . \tag{3}$$

- This rate could enable a measurement of the Gd concentration to a statistical precision of $\sim$2.5%.
- The mean lifetime for μ^- in Gd nuclei is 80.6 ± 0.8 ns which may be hard to measure with current electronics.

Cosmic muon charge ratio

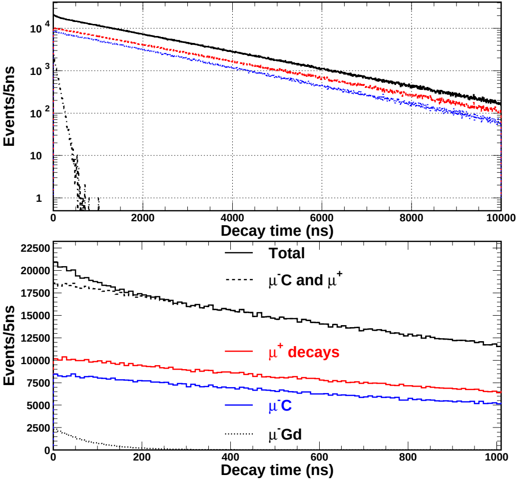
The charge ratio r can be determined from the mean observed lifetime for stopping muons

$$\tau_{\mathrm{m}} = f\tau_{-} + (1-f)\tau_{+} \tag{4}$$

where

- $f = \frac{1}{1+r}$ is the fraction of negative stopped muons,
- $\tau_{+} = 2197.03 \pm 0.04$ ns is the μ^{+} lifetime and
- $\tau_{-} = 2028 \pm 2$ ns is the μ^{-} lifetime in ^{12}C

For a year's exposure of $N = 8 \times 10^{6}$ stopped muons in a single AD, the precision on the μ^{+}/μ^{-} charge ratio would be $\sim$0.024.
For comparison, recent MINOS measurement:
$r = 1.270 \pm 0.003(\mathrm{stat}) \pm 0.013(\mathrm{syst})$



The expected decay time distribution for a background-free, half-year exposure (4×10^6 stopped muons)